V. SCENARIOS SIMULATING THE EFFECTS OF THE PROPOSED PERRYMAN POWER PLANT

A. INTRODUCTION

The proposed Perryman Plant is in the planning stage; thus specifics concerning the design and operations of the plant have not yet been finalized. The proposed plant will likely be a 2- to 4-unit plant with closed-cycle cooling. The source for make-up water will likely involve the use of water from outside the Bush River basin. To date, the greatest amount of attention has focused on the use of water from the Baltimore Water Supply (Conowingo Pond or Loch Raven Reservoir). Since nutrient levels in both Conowingo Pond and Loch Raven Reservoir are relatively high, and cooling tower evaporation would further concentrate nutrients, use of out of basin water could result in a substantial increased total nutrient load to the Bush River. This nutrient load would be in addition to, and in the same vicinity as, the nutrient loading from the Sod Run WWTP.

Another consideration in predicting the effects of nutrient loadings from the proposed Perryman Plant is that the projected on-line date for Perryman is 1998. Therefore, the effects of the Perryman plant must be considered in the context of any likely future events such potential increases in the Sod Run discharge and the possibility of the implementation of pollution abatement practices to improve water quality in Bush River.

In this chapter, we present model analyses used to assess the consequences of increased total nutrient loading from the use of out of basin water to Bush River water quality under present and potential future river conditions.

B. MODEL REPRESENTATION OF PERRYMAN DISCHARGES

Sod Run WWTP and the proposed Perryman facility would both discharge into model Junction 5. The two components to these discharges are flow (mgd or cfs) and constituent concentrations. Table IV-3 shows the flow and constituent concentrations assumed for the Sod Run effluent. Table V-1 shows the flow and constituent concentrations assumed in the Perryman effluent. Flow was estimated based on a 4-unit plant (2,400 MWe) assuming an upper value of 4 mgd/unit. Constituent concentrations in the effluent were estimated as follows. Average monthly nutrient concentrations in Conowingo Pond and Loch Raven Reservoir,

Table V-1. Flow and constituent concentrations assumed for the effluent of a 4-unit Perryman Plant

Month	Flow (cfs)	AMM (mg/L)	NITR (mg/L)	PHOS (mg/L)	CHLORO (µg/L)	CBOD (mg/L)	DO (mg/L)	ORGN (mg/L)	ORGP (mg/L)
March	25	6.8	0	0.6	0	11	10.8	0	0
April	25	6.8	0	0.6	0	11	10.2	0	0
May	25	6.8	0	0.6	0	16	9.2	0	0
June	25	6.8	0	0.6	0	28	8.7	0	0
July	25	6.8	0	0.6	0	17	8.2	0	0
August	25	6.8	0	0.6	0	17	8.1	0	0
September	25	6.8	0	0.6	0	24	8.5	0	0
October	25	6.8	0	0.6	0	13	8.8	0	0
November	25	6.8	0	0.6	0	13	9.7	0	0

Table V-2. Average monthly nutrient concentrations in Conowingo Pond and Loch Raven Reservoir in proximity to the proposed water withdrawal locations for the Perryman Plant. Values for Conowingo Pond are from PECO station 611 (60 ft depth; 1971-1980) and values for Loch Raven Reservoir are from Baltimore Department of Public Works station GUN0142 (0-58 ft depths; 1982-1984).

	Total Nitrogen (mg/L)		Total Phosphorus (mg/L)	
Month	Conowingo[a]	Loch Raven	Conowingo[a]	Loch Raven
March	1.5	1.6	.15	.10
April	1.2	1.9	.12	.06
May	1.3	2.1	.16	.05
June	1.1	1.9	.14	.08
July	1.4	1.9	.11	.08
August	1.2	1.4	.08	.005
September	1.4	1.1	.12	.07
October	1.6	1.5	.13	.04
November	1.5	1.3	.10	.04
Average	1.4	1.6	.12	.06

[a] Estimates based on the following ratios (see Dwyer 1985):
.01 mg N/μg chlorophyll-a
.002 mg P/μg chlorophyll-a
.005 mg N/mg seston
.0015 mg P/mg seston

in proximity to the proposed withdrawal locations, were calculated (Table V-2). Since the nutrient levels in both reservoirs were similar, Conowingo values were used throughout. Nutrient concentrations in the Perryman effluent were estimated using the overall average of the monthly values for March through November in Conowingo Pond, multiplied by a factor of 5 to account for cooling tower evaporation. Further, since the warm temperatures in the cooling towers would favor bacterial decomposition and other breakdown processes, all nitrogen was assumed to be ammonia (AMM) and all phosphorus was assumed to be dissolved inorganic phosphorus (PHOS). Assuming nutrients to be in the ammonia and dissolved inorganic phosphorus forms results in the greatest possible response of added nutrients, since these are the nutrient forms available and, in the case of ammonia, most preferred for algal uptake and chlorophyll-a production. The effect of cooling tower conditions on the remaining constituents (chlorophyll-a (CHLORO), dissolved oxygen (DO), carbonaceous biochemical demand (CBOD)) are unknown. Therefore, chlorophyll-a, dissolved oxygen, and carbonaceous biochemical demand were assumed to be at the same concentrations as in the Sod Run WWTP effluent.

Since both Sod Run and Perryman would discharge into model Junction 5, the nutrient loadings from both discharges should be viewed in the context of a total combined load. Three combinations of Sod Run and Perryman discharges were used with the model results presented in this chapter:

Constituent Loadings Level	Description
I	Sod Run WWTP at 1984 flows and constituent concentrations (Table IV-3)
II	Sod Run WWTP at 1984 flows and constituent concentrations plus a 4-unit Perryman Plant (see Tables IV-3 and V-1)
III	Sod Run WWTP at 1984 flows and constituent concentrations plus a 4-unit Perryman Plant, with 5X the combined nutrient concentrations.

Constituent Loadings Level III was chosen as an arbitrarily high level of nutrient loadings greatly in excess of any likely loadings from the Perryman Plant. As discussed in more detail below, Constituent Loadings Level III is included in order to gain insight into the reasons for the predicted responses of the Bush River to realistic Perryman loadings (Constituent Loadings Level II). The combined constituent loadings from Sod Run and Perryman for these three combinations are shown in Table V-3.

Table V-3. Combined constituent loadings for the Sod Run WWTP and the proposed Perryman Plant at three loading levels. Constituent Loadings Level I is Sod Run WWTP at 1984 flows and constituent concentrations (see Table IV-3), Constituent Loadings Level II is Sod Run WWTP at 1984 values plus a 4-unit Perryman Plant (see Tables IV-3 and V-1), and Constituent Loadings Level III is Sod Run WWTP at 1984 values plus a 4-unit Perryman Plant with 5X the combined nutrient concentrations.

	Constituent Loadings Level I (kg/day)								Constituent Loadings Level II (kg/day)								Constituent Loadings Level III (kg/day)							
Month	AMM	NITR	PHOS	CHLORO	CBOD	DO	ORGN	ORGP	AMM	NITR	PHOS	CHLORO	CBOD	DO	ORGN	ORGP	AMM	NITR	PHOS	CHLORO	CBOD	DO	ORGN	ORGP
March	529	40	16	0	292	286	344	13	946	40	53	0	966	948	344	13	4730	200	265	0	966	948	1720	65
April	559	42	17	0	307	285	363	14	976	42	54	0	981	910	363	14	4880	210	270	0	981	910	1815	70
May	524	39	16	0	419	241	341	13	941	39	53	0	1399	805	341	13	4705	195	265	0	1399	805	1705	65
June	461	35	14	0	645	200	299	12	878	35	51	0	2360	733	299	12	4390	175	255	0	2360	733	1495	60
July	475	36	14	0	404	195	309	12	892	36	51	0	1445	697	309	12	4460	180	255	0	1445	697	1545	60
August	412	31	12	0	350	167	268	10	829	31	49	0	1391	663	268	10	4145	155	245	0	1391	663	1340	50
September	377	29	11	0	453	160	245	9	794	29	48	0	1923	681	245	9	3970	145	240	0	1923	681	1225	45
October	363	27	11	0	236	160	236	9	780	27	48	0	1032	699	236	9	3900	135	240	0	1032	699	1180	45
November	372	28	11	0	242	181	242	9	789	28	48	0	1038	775	242	9	3945	140	240	0	1038	775	1210	45

C. DEFINITION AND IDENTIFICATION OF WORST CASE CONDITIONS

As discussed in Chapter IV, the data available for the Bush River were limited. While the model successfully replayed the water quality dynamics observed during the 1984 Boynton study, 1984 was a year of high freshwater flow (69.3 cfs at USGS station 01581700 on Winter's Run compared to a 17 year average of 54.1 cfs). Also, there is a great deal of uncertainty associated with the tributary and seaward boundary inputs. Assessments of the consequences of increased nutrient loading based on the model calibrated to 1984 conditions may be different from the results of the model calibrated to conditions representative of other years. Model runs with combinations of varied tributary and seaward boundary inputs were made to determine the sensitivity of model results to 1984 calibration conditions, and to identify conditions under which Perryman would have the greatest effect on water quality (i.e., worst case conditions).

In assessments of the effects of nutrient loadings on aquatic systems, worst case conditions are typically defined as those conditions under which increased loadings cause the greatest degradation of water quality (i.e., highest chlorophyll-a and lowest dissolved oxygen concentrations). We term these worst case conditions as absolute worst case conditions. Model inputs are varied to identify the conditions under which the highest chlorophyll-a and lowest dissolved oxygen concentrations are predicted. These conditions are considered worst case conditions and are used as the reference (or baseline) simulations upon which model predictions of chlorophyll-a and dissolved oxygen under increased nutrient loadings are compared to. Since increased nutrients loadings under absolute worst case conditions result in the worst possible water quality conditions, model predictions of the effects of increased loadings are often compared to water quality standards.

In this study, we also investigated an alternative definition of worst case conditions, which we term relative worst case conditions. Relative worst case conditions are those values of model inputs under which increased nutrient loadings cause the greatest change in water quality. Assessment of increased nutrient loadings under relative worst case conditions could be important since these result in the greatest relative change in water quality and could be most obvious to the public.

To illustrate the potential differences between absolute and relative worst case conditions, consider a hypothetical situation where the only model inputs to be varied are water temperature and flow. Suppose these inputs were varied and model analyses showed that under the conditions of low flow and high temperature (summer) the lowest dissolved oxygen concentrations from among all model runs examined were predicted, and the minimum value was 5.5 mg/L. Model results under low flow and high temperature conditions thus serve as the baseline simulation for absolute worst case conditions. Increased nutrient loadings under these conditions cause a reduction in dissolved oxygen to 4.5 mg/L. This small change in dissolved oxygen (from 5.5 to 4.5 mg/L) is likely not perceptible to the public; yet the reduction in dissolved oxygen is important because now the Maryland State Standard of 5.0 mg/L is violated. Under different conditions, say high flow and high temperature, the model predicts dissolved oxygen concentrations in excess of 9.0 mg/L. Increased nutrient loadings under these conditions cause dissolved oxygen to be reduced from 9.0 to 5.5 mg/L. This relative large change in dissolved oxygen does not result in violations of state water quality standards, but may cause changes in the system perceptible by the public (e.g., shifts in species composition).

Both absolute and relative worst case conditions can be determined by varying model inputs and identifying the combinations of model inputs which result in the highest and lowest chlorophyll-a and dissolved oxygen concentrations (i.e., the extremes). Absolute worst case conditions may or may not be identical to the conditions of relative worst case conditions. Absolute worst case conditions for chlorophyll-a would be the combination of model inputs which resulted in the highest chlorophyll-a concentrations. Under these conditions, any increases in chlorophyll-a due to increased nutrient loadings would result in the absolute highest possible chlorophyll-a concentrations. In a similar manner, the absolute worst case conditions for dissolved oxygen are the combination of model inputs which produced the lowest dissolved oxygen concentrations. If increased nutrient loadings caused a reduction in dissolved oxygen, then under these conditions increased nutrient loadings would result in the absolute lowest possible DO values.

Identification of the relative worst case conditions is not as straightforward as identification of absolute worst case conditions. The greatest relative changes in chlorophyll-a and dissolved oxygen due to increased nutrient loadings could occur under any conditions. Situations can be envisioned under which the greatest relative change in chlorophyll-a could occur when chlorophyll-a concentrations are lowest. For example, if nutrients are limiting chlorophyll-a production, then under low chlorophyll-a conditions added nutrients would result in an increase in chlorophyll-a. However, under high chlorophyll-a concentrations, it is possible for light to be limiting due to algal self-shading. Added nutrients under these conditions would have little effect on chlorophyll-a. Situations can also be envisioned when the greatest relative effects on chlorophyll-a occur under conditions of high chlorophyll-a concentrations. If the system only becomes nutrient limited when chlorophyll-a concentrations are high (i.e., algal uptake has depleted available nutrients), then added nutrients would have little effect under low chlorophyll-a conditions, but a great effect under high chlorophyll-a concentrations. Similar arguments can be made for relative worst case conditions occurring under other than extreme conditions. However, we can assume that if we examine the effects of increased nutrient loadings under typical (i.e., calibration) conditions and extreme conditions, we are likely to have observed the relative worst case conditions, or at least conditions close to the relative worst case conditions.

Tributary and seaward boundary model inputs that were varied to identify potential worst case conditions, and their values, were:

Condition A - Tributary inflows at values estimated from USGS station 01581700 during 1981, a year of relatively low freshwater flow (average flow of 21.5 cfs compared to a 17 year average of 54.1 cfs)

Condition B - Tributary constituent concentrations (except DO) at 5X the values used for the 1984 model calibration

Condition C - Tributary constituent concentrations (except DO) at 0.2X the values used for the 1984 model calibration

Condition D - Seaward constituent concentrations (except DO) at 0.2X the values used for the 1984 model calibration

Condition E - Seaward constituent concentrations (except DO) at 2X the values used for the 1984 model calibration.

These values of model inputs were chosen in order to include realistic but extreme conditions of high and low nutrient inputs from tributaries and the seaward boundary. Values of dissolved oxygen were not varied under conditions B-E. Dissolved oxygen concentrations are physically constrained to be between 0 and about 12 mg/L (saturation). Furthermore, dissolved oxygen concentrations in the tributaries to, and the seaward boundary of, the Bush River are more likely between 5-9 mg/L. Variation of dissolved oxygen in the same manner as the other constituents under conditions B-E would result in unrealistic values. Seaward boundary constituent concentrations were increased by 2X under condition E (rather than 5X as was done for tributary concentrations under condition B) to reflect our relatively high confidence in Boynton's measurements at the seaward boundary.

A number of other conditions were evaluated as possible worst case conditions, but were eliminated from consideration for various reasons. Among these were scenarios involving changes in the water volume and circulation of the estuary due to wind-induced sea level changes at the boundary. It was felt initially that changes in water volume could either concentrate or dilute constituent loadings entering the river and subsequently affect simulations. However, the volume changes predicted by the Hydraulic Module under wind driven conditions (Appendix A) were so small that concentration changes would be insignificant. Meteorologically forced conditions were thus eliminated from consideration as worst case conditions.

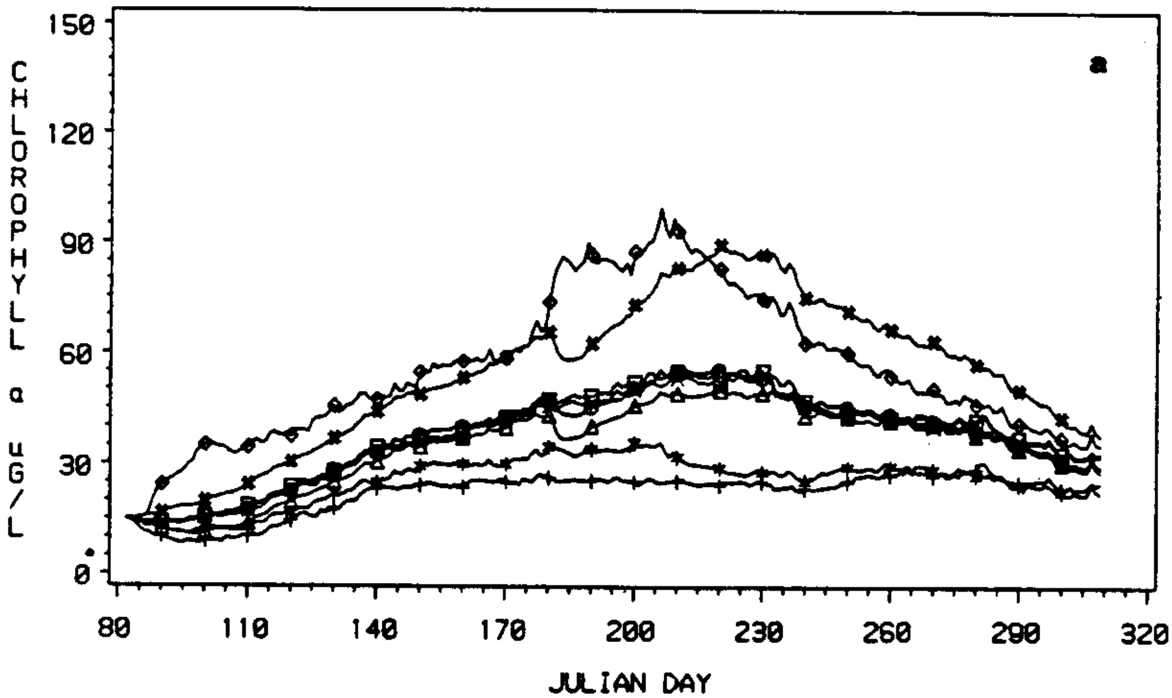
The model was run using the 1984 calibration run under conditions A-E individually, and the combinations of A and C (A/C), A, C, and D (A/C/D), and B and E (B/E). These combinations of conditions were selected because they result in scenarios that include simultaneously high nutrient inputs from the tributaries and seaward boundary and simultaneously low inputs from the tributaries and seaward boundary. Model runs with conditions A, C, D, A/C, and A/C/D represent scenarios that would result in lower nutrient concentrations in the river compared to the 1984 calibration run. Model runs with conditions B, E, and B/E represent scenarios of high tributary and seaward boundary nutrient inputs.

Model predictions of chlorophyll-a (CHLORO) and dissolved oxygen (DO) in Junctions 5 and 7 for model runs under conditions A, B, C, D, E, A/C, and A/C/D are shown in Figs. V-1 and V-2. Included for comparison are the model results from the 1984 calibration run. Model results under condition B/E are not shown because these conditions resulted in unrealistically high values of chlorophyll-a.

Results from Junctions 5 and 7 are shown since, as discussed above, the greatest effect on water quality would be expected in the region of the discharge (Junction 5), and Junction 7 is the area of the river likely to be particularly sensitive to altered nutrient concentrations.

Examination of Figs. V-1 and V-2 shows that model predictions of DO were relatively insensitive to variations in tributary and seaward boundary inputs. The highest and lowest dissolved oxygen concentrations were predicted in Junction 7 under conditions B and A/C/D, respectively. Therefore, absolute worst case conditions for dissolved oxygen would occur under condition A/C/D (i.e., lowest dissolved oxygen concentrations) and relative worst case conditions under the calibration run, condition A/C/D, or condition B (i.e., the typical, highest, and lowest dissolved oxygen concentrations).

Extreme values of model predictions of chlorophyll-a also occurred under conditions B and A/C/D, with the highest chlorophyll-a concentrations predicted under condition B, and the lowest values predicted under condition A/C/D (Figs. V-1



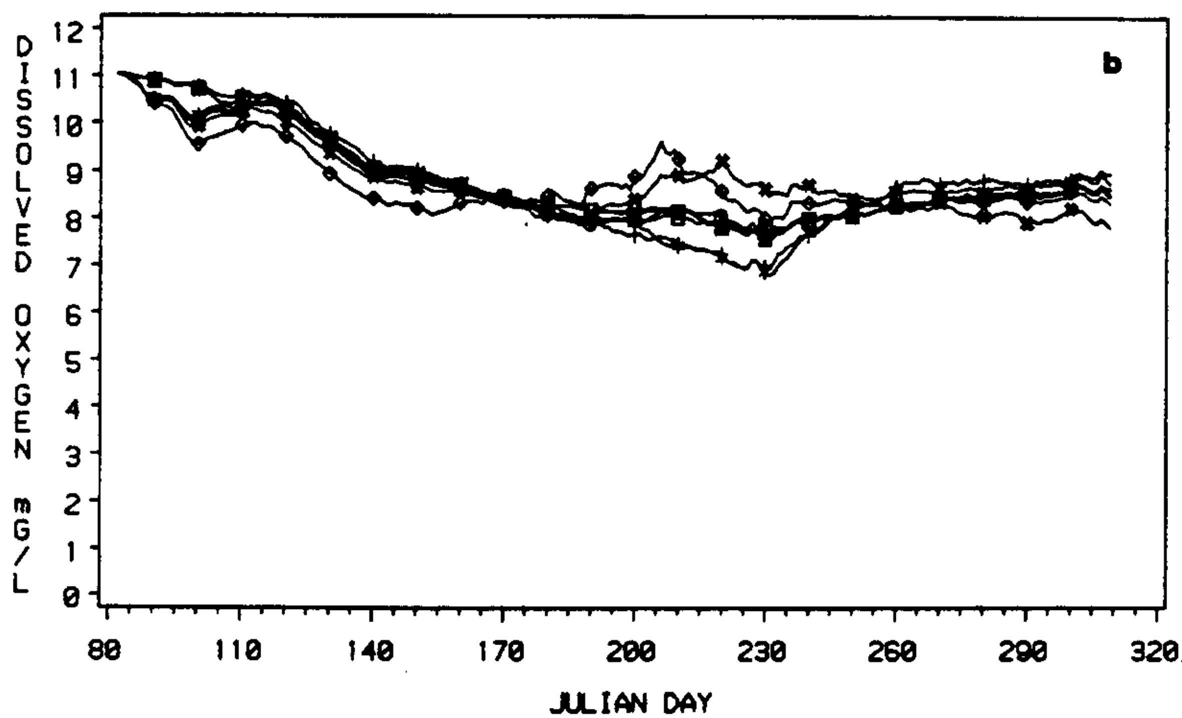


Figure V-1. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 5 for the 1984 calibration run (⊕) and model runs under conditions A (◻), B (◇), C (Δ), D (*), E (#), A/C (X), and A/C/D (+). (See text for definitions of conditions.)

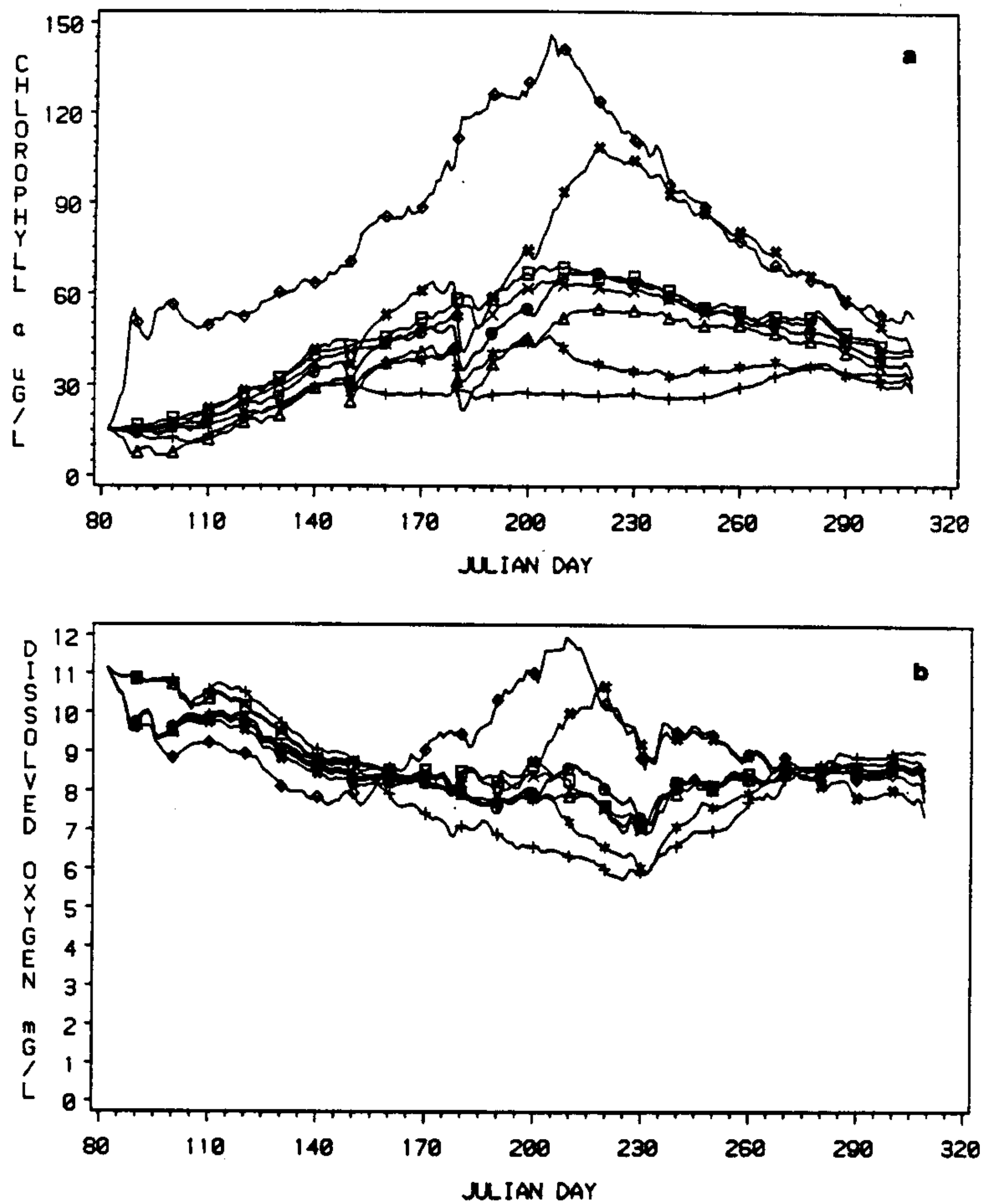


Figure V-2. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 7 for the 1984 calibration run (⊕) and model runs under conditions A (□), B (◇), C (Δ), D (*), E (#), A/C (X), and A/C/D (+). (See text for definitions of conditions.)

and V-2). In the case of chlorophyll-a, the effects of increased nutrient loadings on chlorophyll-a under condition B would provide an assessment under absolute worst case conditions, and under the calibration run, condition B, or condition A/C/D provide relative worst case conditions.

D. PERRYMAN SCENARIOS UNDER PRESENT AND WORST CASE CONDITIONS

Model Predictions

To assess the effects of increased nutrient loadings on Bush River water quality, the model was run with various nutrient loading levels under the following conditions:

- 1984 calibration run - representative of present water quality conditions in the Bush River
- Condition A/C/D - serves as absolute worst case conditions for dissolved oxygen and conditions of lowest possible chlorophyll-a concentrations
- Condition B - serves as absolute worst case conditions for chlorophyll-a concentrations and highest possible dissolved oxygen concentrations.

Results from these runs are presented in Figs. V-3 to V-6. Figures V-3 and V-4 show model-generated values of chlorophyll-a and dissolved oxygen in Junctions 5 and 7 for:

- The 1984 calibration run
- Model runs under conditions B and A/C/D
- Model runs with nutrient loadings equivalent to a 4-unit Perryman Plant (Constituent Loadings Level II) under calibration conditions and conditions B and A/C/D.

In addition to model predictions of the daily average dissolved oxygen concentrations (Figs. V-3a, V-3b, V-4a, and V-4b), the daily range of dissolved oxygen values predicted by the model are included for the absolute worst case conditions for dissolved oxygen (condition A/C/D) (Figs. V-3c and V-4c).

Comparing the model runs that include nutrient loadings from a Perryman plant (Constituent Loadings Level II) to runs without Perryman shows that, regardless of the assumed conditions, Perryman discharges only cause slight increases in chlorophyll-a and dissolved oxygen. Furthermore, under no conditions are

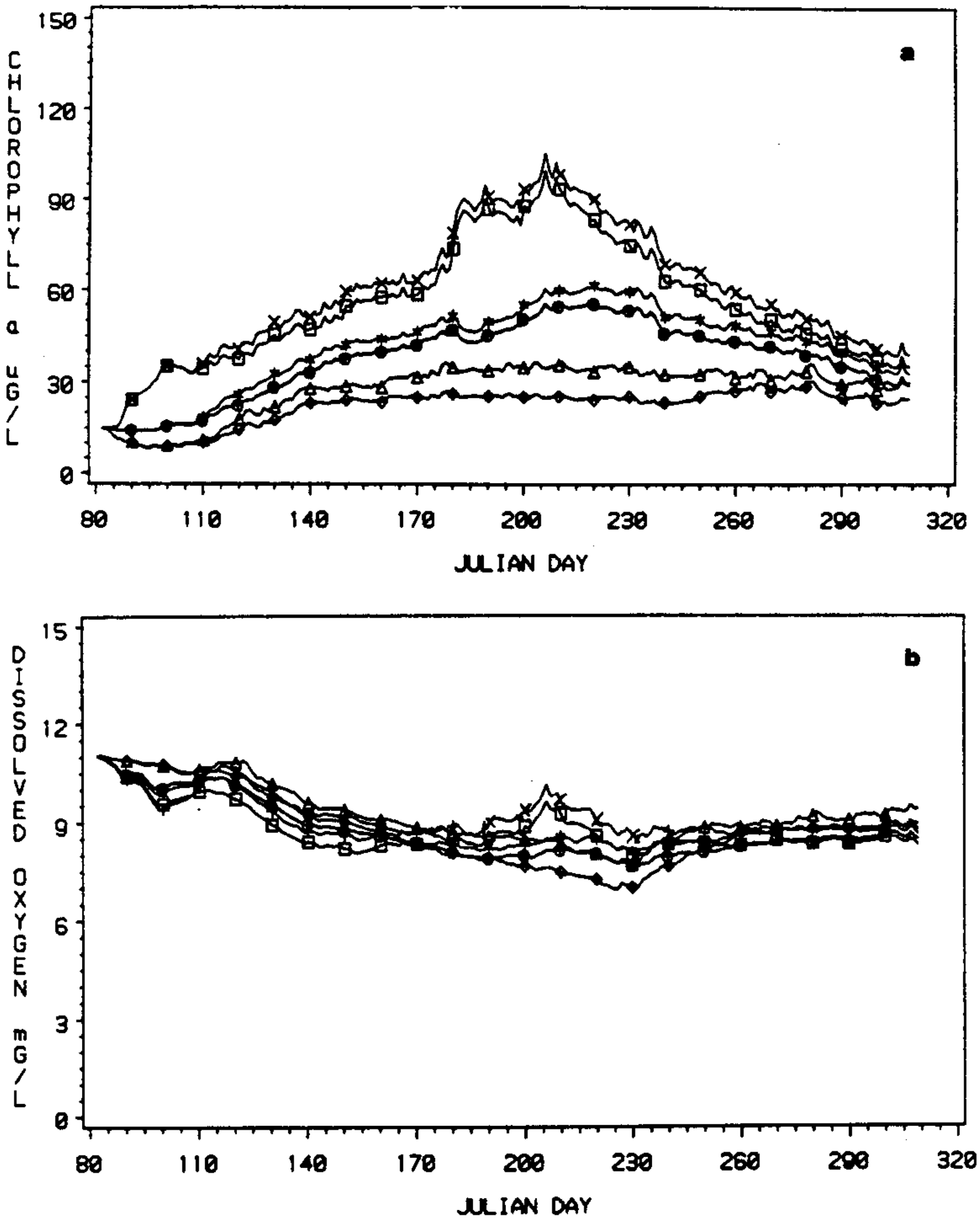


Figure V-3. Model predictions of chlorophyll-a and dissolved oxygen in Junction 5 for the 1984 calibration run, model runs under conditions B and A/C/D, and each of these runs with the additional nutrient loading equivalent to a 4-unit Perryman Plant (Constituent Loadings Level II). 1984 calibration run (⊕ = without Perryman; * = with Perryman), Condition B (□ = without Perryman; X = with Perryman), and condition A/C/D (◇ = without Perryman; Δ = with Perryman). (a) chlorophyll-a (CHLORO), (b) dissolved oxygen (DO), and (c) daily range of DO values for runs under condition A/C/D.

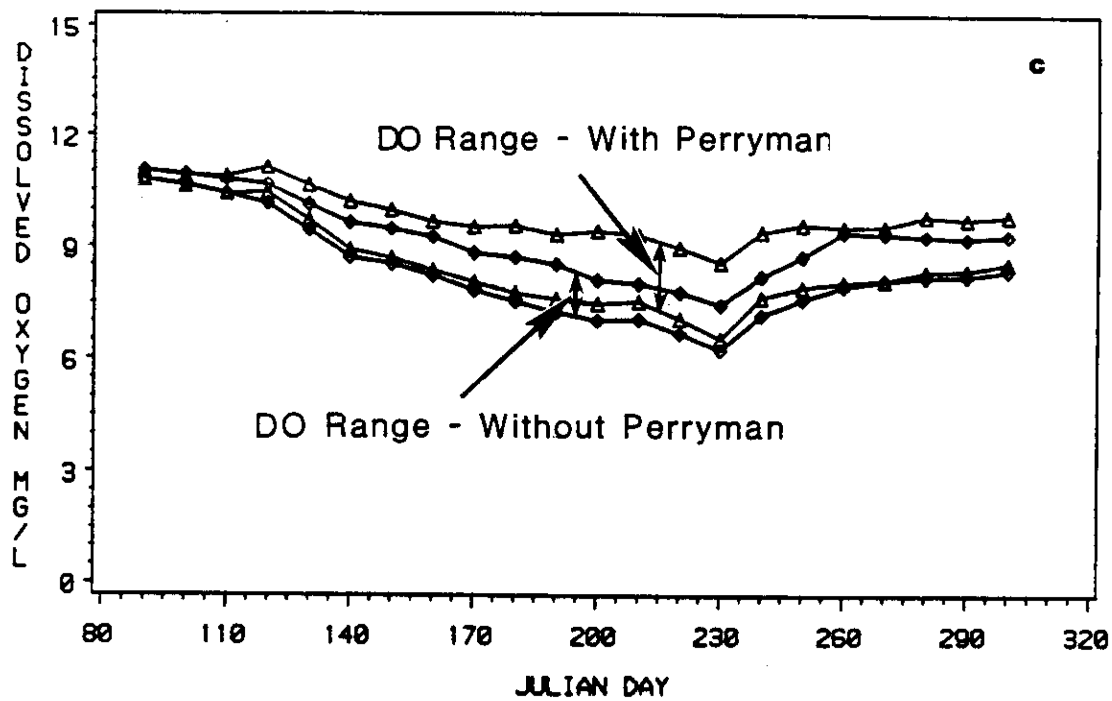


Figure V-3. Continued

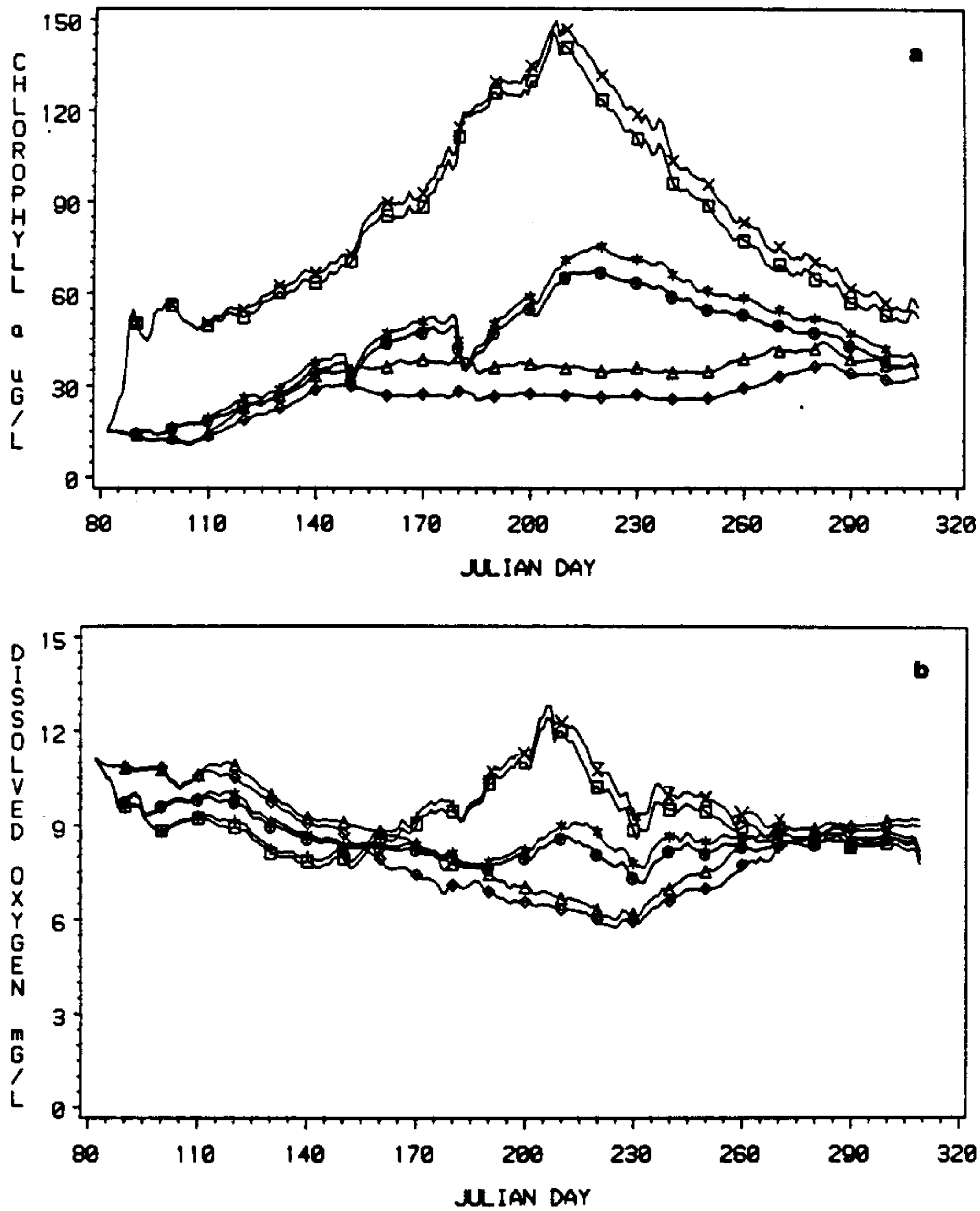


Figure V-4. Model predictions of chlorophyll-a and dissolved oxygen in Junction 7 for the 1984 calibration run, model runs under conditions B and A/C/D, and each of these runs with the additional nutrient loading equivalent to a 4-unit Perryman Plant (Constituent Loadings Level II). 1984 calibration run (⊕ = without Perryman; * = with Perryman), Condition B (□ = without Perryman; X = with Perryman), and condition A/C/D (◇ = without Perryman; Δ = with Perryman). (a) chlorophyll-a (CHLORO), (b) dissolved oxygen (DO), and (c) daily range of DO values for runs under condition A/C/D.

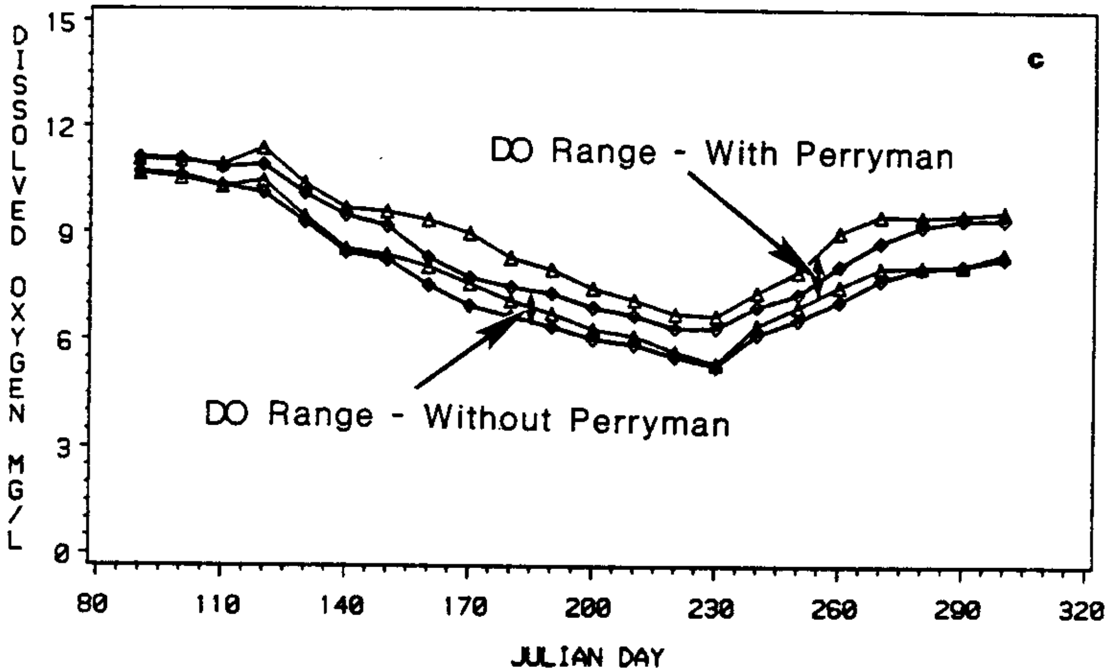


Figure V-4. Continued

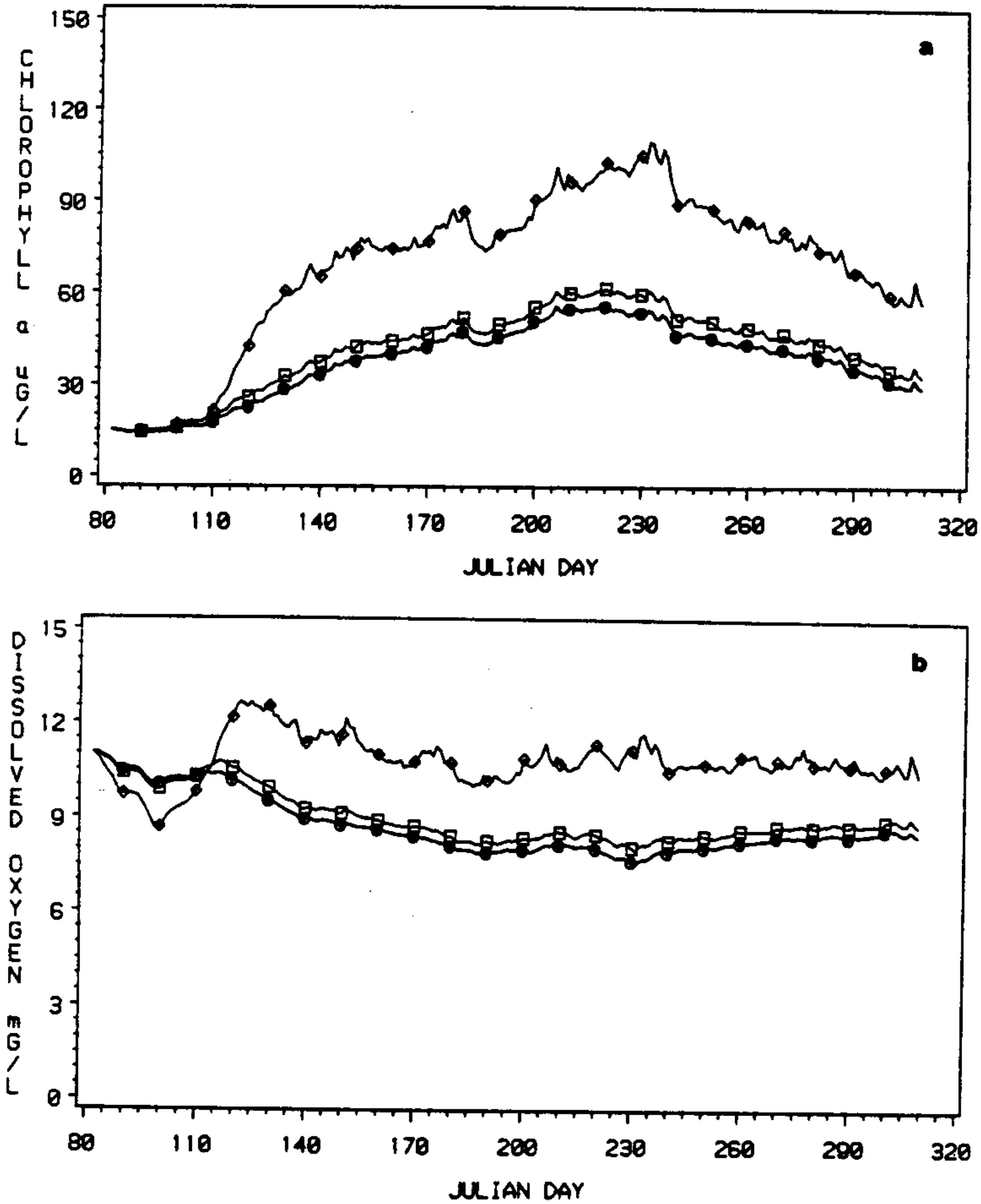


Figure V-5. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 5 for the 1984 calibration run (⊕), the 1984 calibration run with increased nutrient loadings equivalent to a 4-unit Perryman Plant (□ ; Constituent Loadings Level II), and the 1984 calibration run with loadings equivalent to 5X the combined nutrient loadings from Sod Run WWTP and a 4-unit Perryman Plant (◇ ; Constituent Loadings Level III).

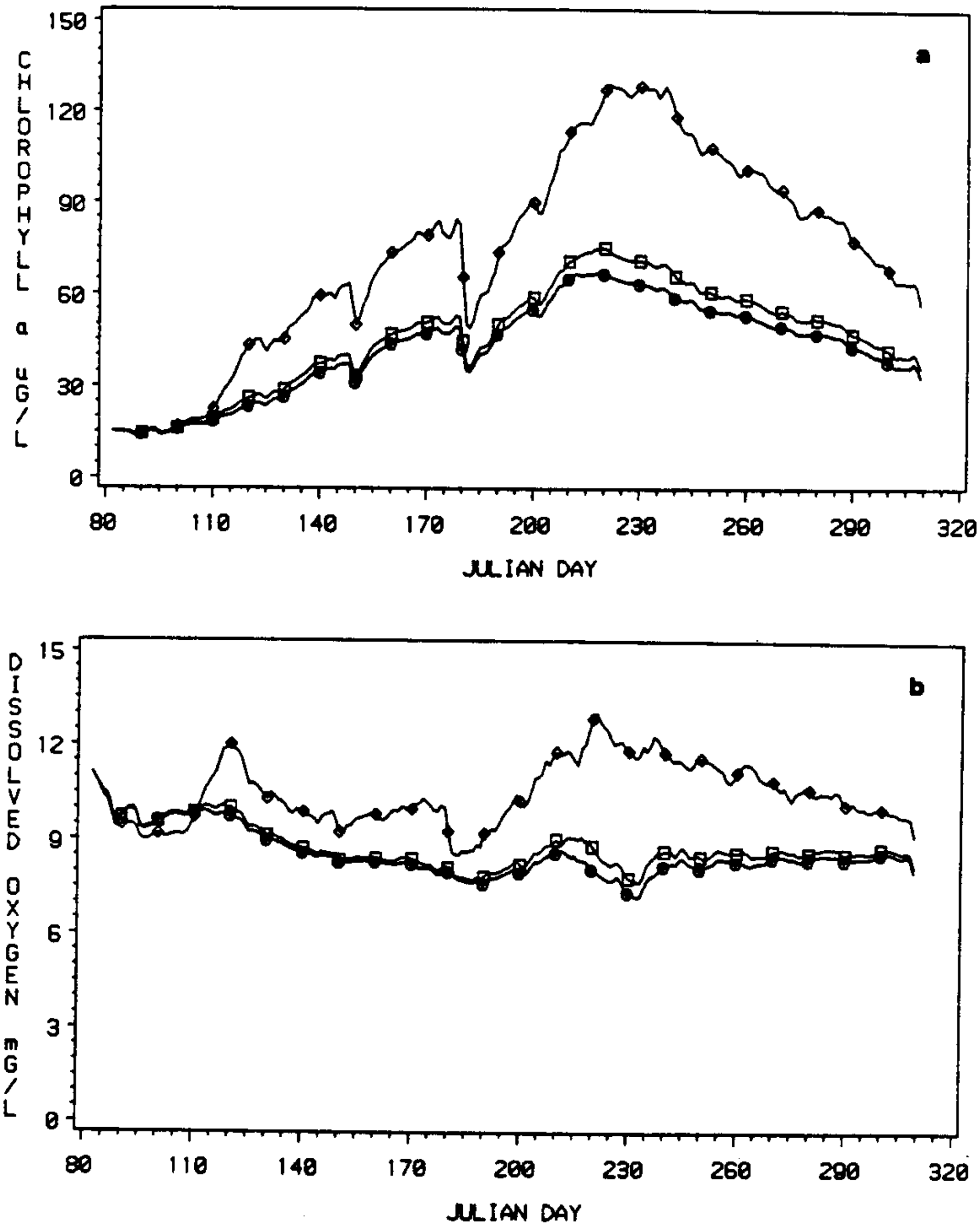


Figure V-6. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 7 for the 1984 calibration run (⊕), the 1984 calibration run with increased nutrient loadings equivalent to a 4-unit Perryman Plant (□ ; Constituent Loadings Level II), and the 1984 calibration run with loadings equivalent to 5X the combined nutrient loadings from Sod Run WWTP and a 4-unit Perryman Plant (◇ ; Constituent Loadings Level III).

predicted DO values below the state of Maryland standard of 5.0 mg/L. As illustrated in Figs. V-3c and V-4c, the daily ranges of DO values predicted by the model are small. Based on the model's underestimation of net daytime oxygen production and nighttime oxygen consumption rates during the summer compared to rates measured during the 1984 Boynton study (Figs. IV-9 and IV-10), the small range of values predicted by the model are likely underestimates of the daily range of DO concentrations in the Bush River. However, model predictions of the daily ranges of DO concentration during the summer (for example, as shown in Figs. V-3c and V-4c) are similar to concentrations measured during a 1985 study (see Appendix C). For instance, using DO concentrations measured at 1-m depth intervals at seven times during each of two different 24-hr periods (17-18 July, 28-29 August), minimum and maximum values of depth averaged DO concentrations at a station located in Junction 5 ranged from 5.9-8.2 mg/L on 17-18 July and 6.1-9.8 mg/L on 28-29 August. These DO ranges are similar to model predictions of DO ranges for Junction 5 shown in Fig. V-3c. Depth averaged concentrations are compared to model values because model predictions are average concentrations for the entire water column. Thus, while the model likely underestimates the daily ranges of DO concentrations in the Bush River, based on the limited data available model predictions appear to be reasonable.

Two possible explanations for the small effects of the Perryman Plant are:

- Algae are limited by factors other than nutrients (e.g., light, temperature), and thus added nutrients cannot be used by the algae, or

- The magnitude of the estimated nutrient loadings from a Perryman Plant are small relative to the volume of the receiving waters.

Establishing which of these two explanations accounts for the small effects of the Perryman Plant on chlorophyll-a and dissolved oxygen was done by examining predictions of chlorophyll-a and dissolved oxygen for a model run with 5X the combined nutrient loadings from Sod Run WWTP and a 4-unit Perryman Plant (Constituent Loadings Level III) (Figs. V-5 and V-6). The model predicts substantially higher chlorophyll-a concentrations with the 5X nutrient loadings. Thus, present conditions in the Bush River allow for significantly higher chlorophyll-a concentrations. Therefore, it appears that the small effects predicted by the model for a 4-unit Perryman Plant are due to the small magnitude of the estimated nutrient loadings relative to the volume of the receiving waters, rather than due to factors other than nutrients limiting chlorophyll-a production.

It is somewhat surprising that the small effects predicted for the Perryman Plant are due to the small magnitude of the

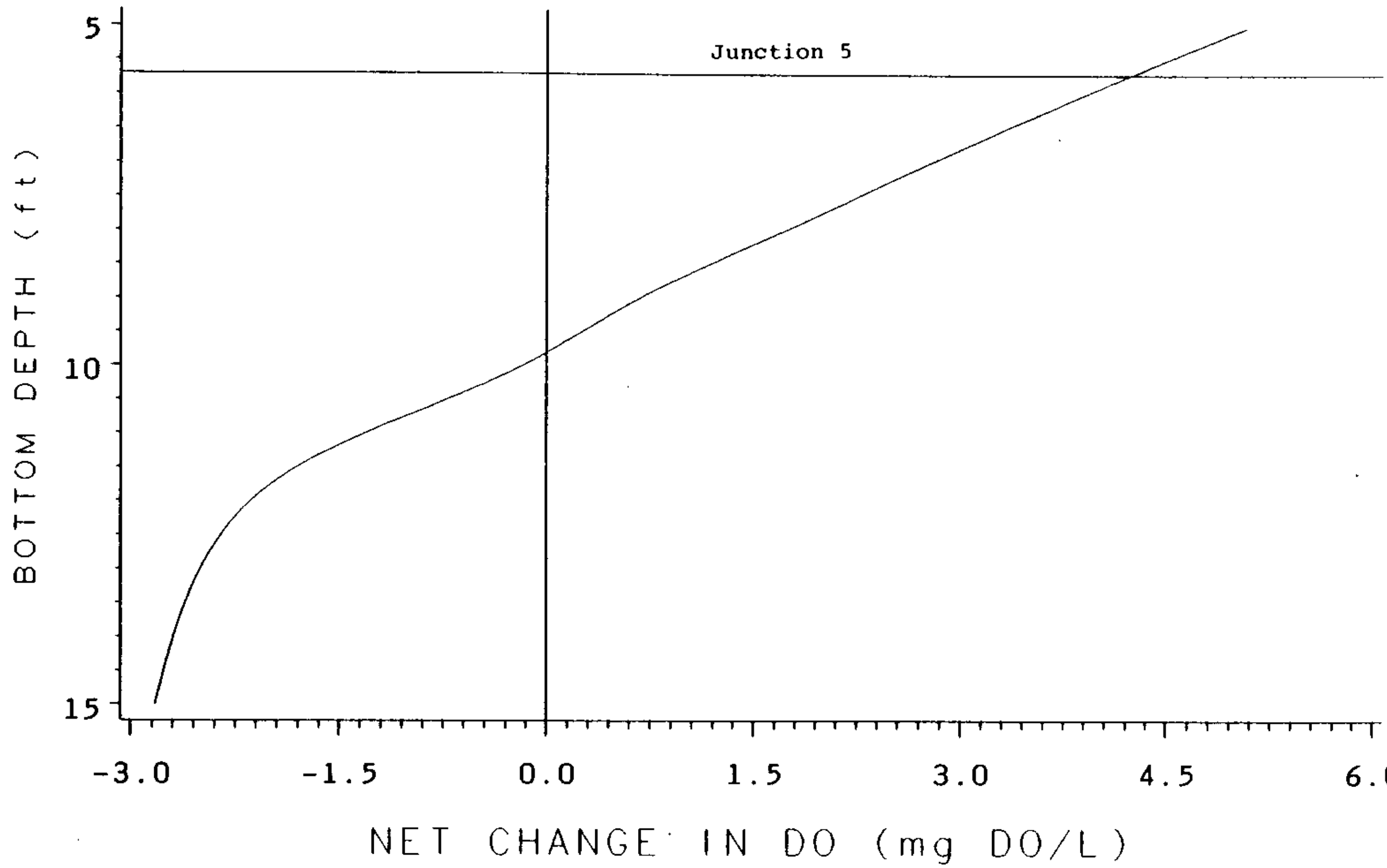
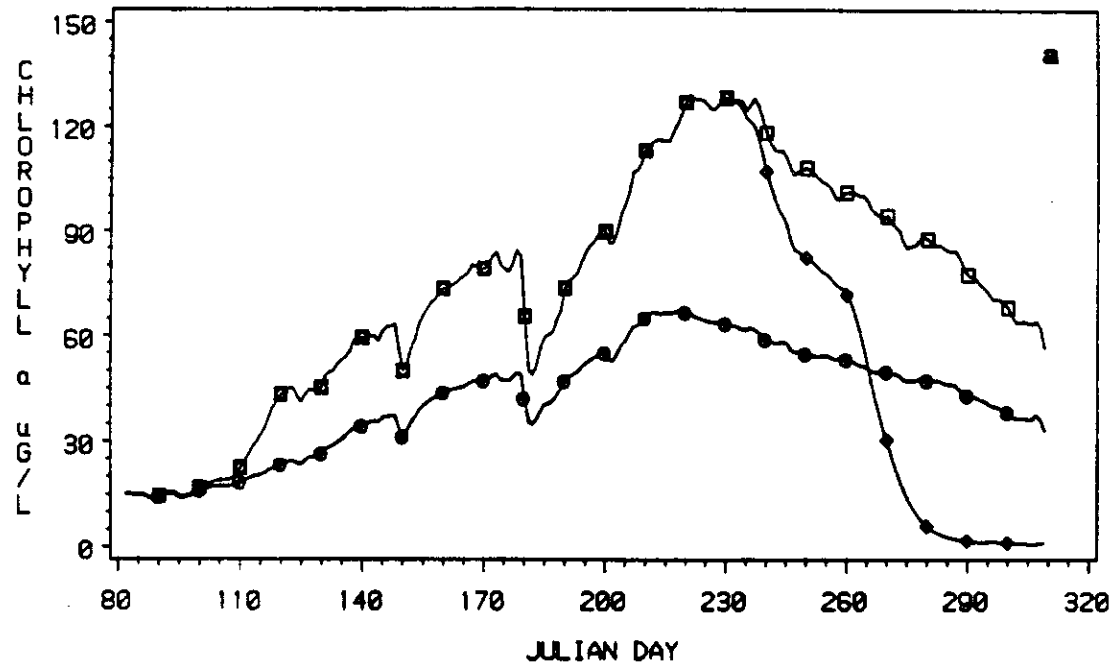


Figure V-7. Net change in dissolved oxygen concentration predicted by the model for Julian Day 180 in Junction 5 under Constituent Loadings Level III for hypothetical bottom depths of 5-15 ft. Net changes in dissolved oxygen were calculated ignoring reaeration, advection, dispersion, and effects on photosynthesis due to cloud cover attenuation of incident light and nutrient limitation.



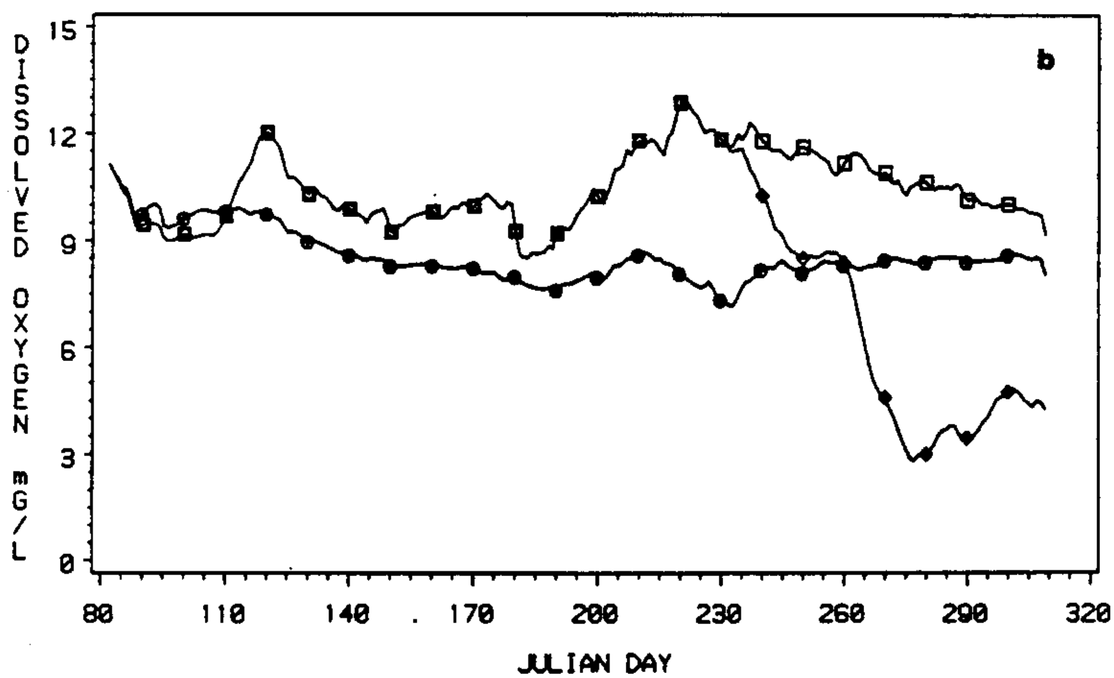
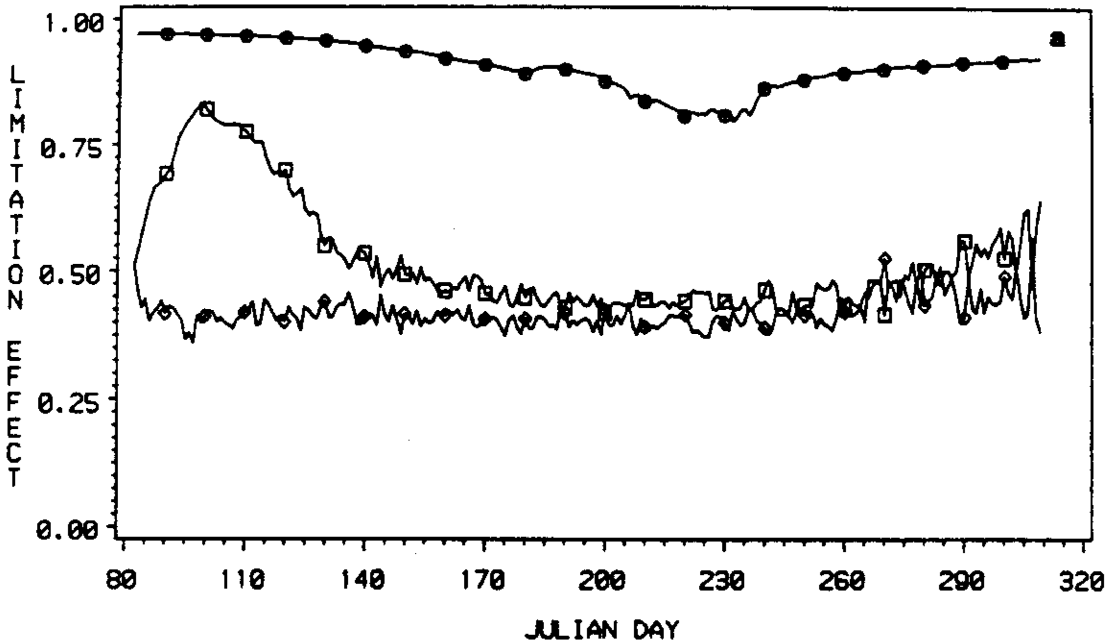


Figure V-8. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 7 for the 1984 calibration run (⊕), the 1984 calibration run with increased nutrient loadings equivalent to 5X the combined loadings of Sod Run WWTP and a 4-unit Perryman Plant (; Constituent Loadings Level III), and the 1984 calibration run with 5X the combined loadings but with chlorophyll-a forced to decay to zero beginning at day 230 (◊).

expected nutrient loadings. Recently, state agencies and citizen's groups have expressed concern over any expansion of the Sod Run WWTP (see CH2M Hill 1983). The estimated dissolved inorganic nitrogen (ammonia + nitrite/nitrate) from a 4-unit Perryman Plant used in model runs are similar to those from the current Sod Run WWTP discharge, and the dissolved inorganic phosphorus loadings are over 2.5 times higher than the loadings from the Sod Run WWTP. Yet, according to the model, the incremental increase in loadings from a 4-unit Perryman Plant over those from the Sod Run WWTP have little effect on chlorophyll-a and dissolved oxygen in the Bush River.

Interestingly, under both Constituent Loadings Levels II and III, higher average dissolved oxygen concentrations are predicted compared to the 1984 calibration run. Increased dissolved oxygen concentrations result from increased nutrients causing increased chlorophyll-a production. Even under conditions of high chlorophyll-a concentrations, the Bush River is shallow enough that light extinction with depth results in sufficient light throughout the water column such that on a daily basis, dissolved oxygen added by photosynthesis exceeds the losses of dissolved oxygen due to algal respiration, nitrification, sediment oxygen demand, and carbonaceous biochemical oxygen demand. Figure V-7 shows the net change in dissolved oxygen concentration (photosynthesis - algal respiration - nitrification - sediment oxygen demand - carbonaceous biochemical oxygen demand) predicted by the model for Julian Day 180 in Junction 5 under Constituent Loadings Level III for hypothetical bottom depths of 5-15 ft. Net changes in dissolved oxygen shown in Fig. V-7 were calculated ignoring reaeration, advection, dispersion, and effects on photosynthesis due cloud cover attenuation of incident light and nutrient limitation. Figure V-7 shows that with a bottom depth of 5-6 ft. in Junction 5, there would be a net gain of dissolved oxygen of about 4 mg/L during Julian Day 180. Only with an assumed bottom depth of >10 ft do dissolved oxygen losses exceed the increase in dissolved oxygen due to photosynthesis. At bottom depths of >10 ft, the extinction of light with depth is sufficient that enough of the water column experiences suboptimal light intensities thereby causing the water column integrated production of dissolved oxygen due to photosynthesis to be less than the losses of dissolved oxygen. Thus the increased daily dissolved oxygen values predicted by the model under conditions of high chlorophyll-a concentrations are due to the shallow bottom depths of the Bush River estuary resulting in sufficient light throughout the water column for dissolved oxygen production (due to photosynthesis) to exceed losses.

It is possible for increased nutrient loadings to cause a reduction in dissolved oxygen concentrations in the Bush River estuary. This could arise if conditions in the river resulted in the complete conversion of the algal biomass at



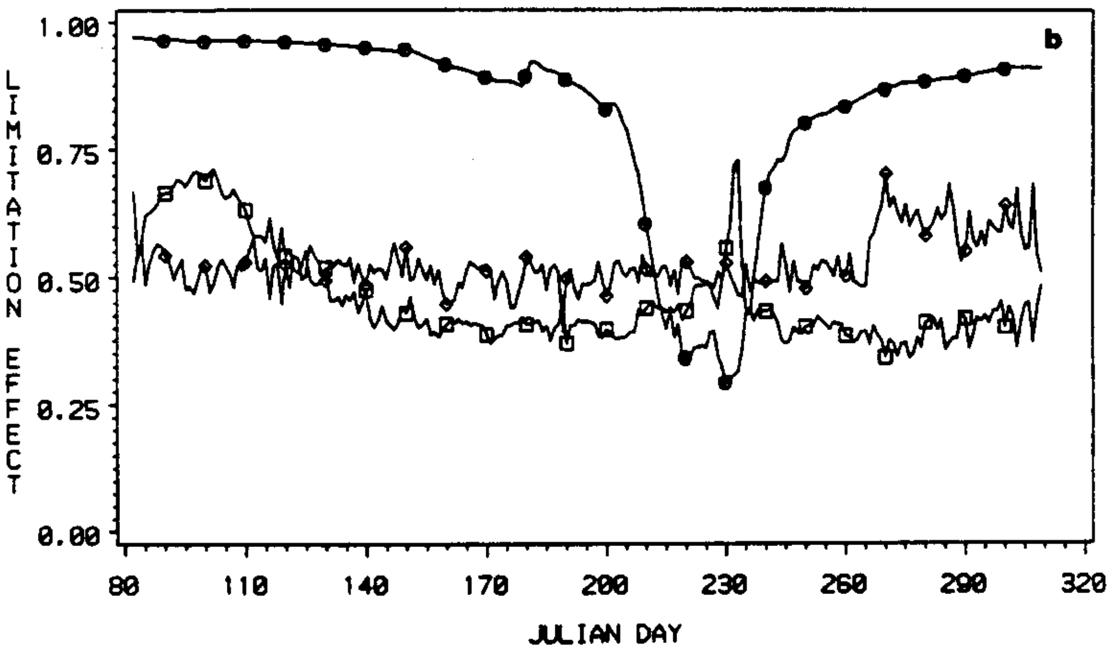


Figure V-9. Light (◊), nitrogen (⊕), and phosphorus (□) limitation terms for algal photosynthesis (averaged between sunrise and sunset) for the 1984 calibration run. (a) Junction 5 and (b) Junction 7.

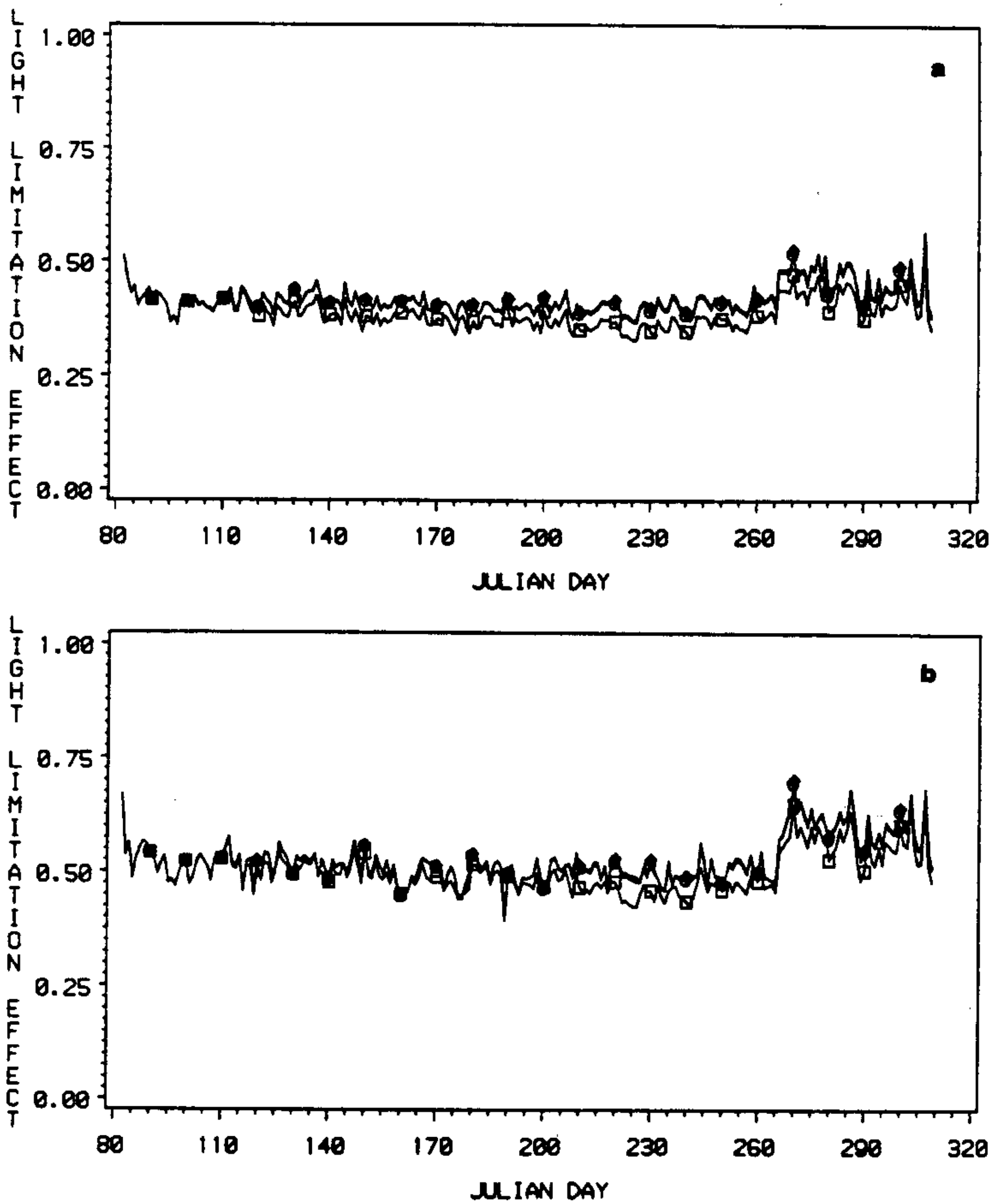


Figure V-10. Light limitation term for algal photosynthesis for the 1984 calibration run (◊), the 1984 calibration run with increased nutrient loadings equivalent to a 4-unit Perryman Plant (⊕; Constituent Loadings Level II), and the 1984 calibration run with loadings equivalent to 5X the combined nutrient loadings of Sod Run WWTP and a 4-unit Perryman Plant (□ ; Constituent Loadings Level III). (a) Junction 5 and (b) Junction 7.

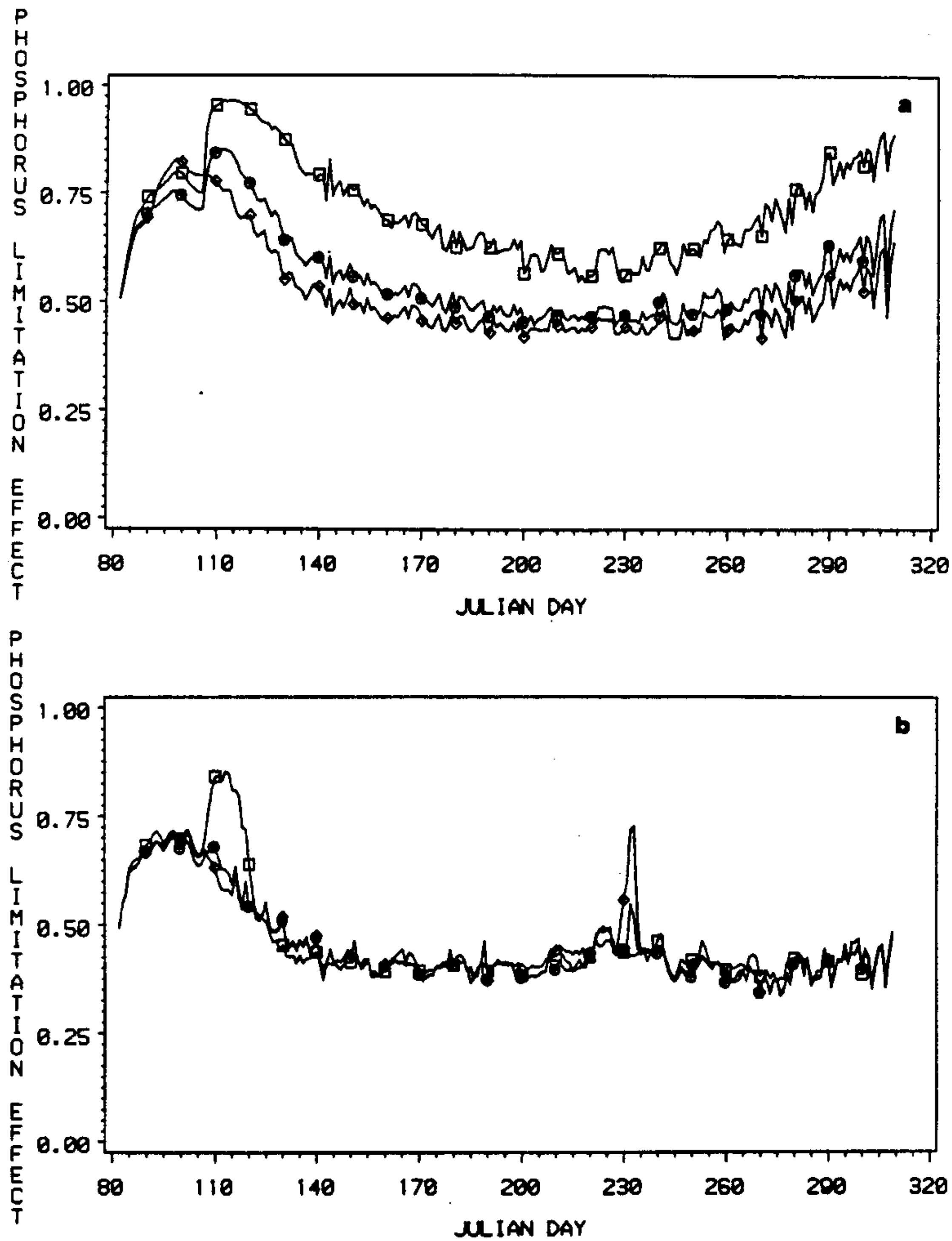


Figure V-11. Phosphorus limitation term for algal photosynthesis for the 1984 calibration run (◊), the 1984 calibration run with increased nutrient loadings equivalent to a 4-unit Perryman Plant (⊕; Constituent Loadings Level II), and the 1984 calibration run with loadings equivalent to 5X the combined nutrient loadings of Sod Run WWTP and a 4-unit Perryman Plant (□ ; Constituent Loadings Level III). (a) Junction 5 and (b) Junction 7.

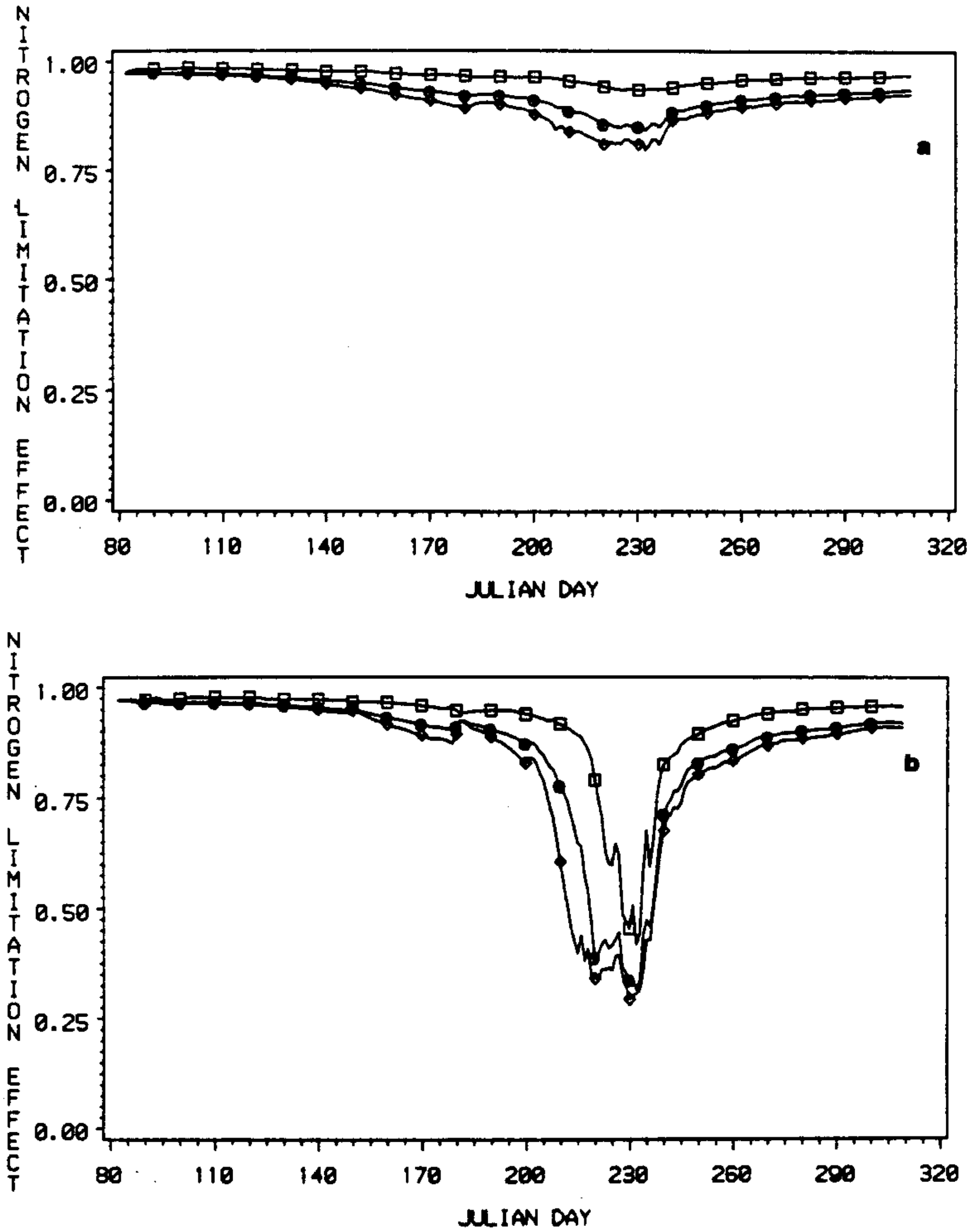


Figure V-12. Nitrogen limitation term for algal photosynthesis for the 1984 calibration run (◊), the 1984 calibration run with increased nutrient loadings equivalent to a 4-unit Perryman Plant (⊕; Constituent Loadings Level II), and the 1984 calibration run with loadings equivalent to 5X the combined nutrient loadings of Sod Run WWTP and a 4-unit Perryman Plant (□ ; Constituent Loadings Level III). (a) Junction 5 and (b) Junction 7.

high chlorophyll-a concentrations to detritus and subsequently to CBOD. Fig. V-8 shows model predictions of chlorophyll-a and dissolved oxygen in Junction 7 for a model run in which, beginning at day 230, chlorophyll-a was converted to detritus such that no chlorophyll-a was left by the end of the simulation. Under these conditions, increased nutrient loadings result in significantly lower daily average oxygen concentrations relative to the results of the 1984 calibration run. Furthermore, the predicted values are less than the state of Maryland standard of 5.0 mg/L for a substantial period of time.

Examples of conditions that could lead to complete conversion of chlorophyll-a to detritus during the summer months are extremely high turbidity levels (causing increased light extinction with depth) and an additional source of algal mortality not included in the model (e.g., toxicant induced). While complete conversion of chlorophyll-a to detritus results in low dissolved oxygen concentrations, based on the limited historical data that are available for the Bush River, such events are unlikely.

Explanation of Predicted Chlorophyll-a Increases

Given that the Bush River ecosystem can, under high enough nutrient loadings (e.g., Constituent Loadings Level III), exhibit substantial increases in chlorophyll-a, it is useful to understand the processes which result in these increased chlorophyll-a levels.

Figure V-9 shows the light limitation, nitrogen limitation, and phosphorus limitation terms (averaged between sunrise and sunset) for the 1984 calibration run. Figures V-10 to V-12 compare the light, nitrogen, and phosphorus limitation terms for the same three runs as in Figs. V-3 and V-4 (1984 calibration run, 1984 calibration with a 4-unit Perryman Plant, and 1984 calibration run with 5X the combined nutrient loadings). Recall that chlorophyll-a production is calculated as a maximum rate (adjusted for temperature) multiplied by the light limitation term and the minimum of the nitrogen and phosphorus terms. Increased nutrient availability (due to nutrient loadings) results in an increase in the magnitude of the associated nutrient limitation term. If the same nutrient is limiting chlorophyll-a production, then the increased magnitude of the limitation term results in an increased chlorophyll-a production rate.

In general, Fig. V-9 shows that, under 1984 calibration conditions, the algal production of chlorophyll-a is limited by phosphorus and light. The only exception is in Junction 7 around day 230, during which nitrogen becomes more limiting than phosphorus. The increased chlorophyll-a in Junctions 5 and 7 under the 5X combined nutrient loadings are caused by somewhat different processes (Figs. V-10 to V-12). In Junction 5, the added phosphorus acts to increase the phosphorus limitation term, allowing increased levels of chlorophyll-a to be produced (Fig. V-11a). In contrast, the phosphorus limitation terms in Junction 7 are similar for all of the nutrient loading levels. Furthermore, light limitation is essentially unaffected in Junctions 5 and 7 by variation of chlorophyll-a concentrations (Fig. V-10). Recall that the total extinction of water is calculated as the sum of background extinction and a term proportional to chlorophyll-a concentration (i.e., self-shading) (see Eq. III.13). Most of the light extinction is due to the background extinction parameter (BACKKE) rather than to self shading. Therefore, most of the increased chlorophyll-a in Junction 7 under the 5X total nutrient loadings is due to the production of chlorophyll-a in Junction 5 and its subsequent upstream transport into Junction 7. An exception to this is between days 210 to 240 when upstream transport of nitrogen from Junction 5 results in an increased nitrogen limitation term during the period of time chlorophyll-a production in Junction 7 is nitrogen limited (Fig. V-12b).

In summary, under present water quality conditions in the Bush River, the likely nutrient loadings from a 4-unit Perryman Plant should have little effect on dissolved oxygen and chlorophyll-a concentrations in the Bush River. However, the prediction of Perryman having little effect on chlorophyll-a and dissolved oxygen is not due to the inability of the model to predict higher chlorophyll-a and lower dissolved oxygen concentrations in the Bush River. Under nutrient loadings greatly in excess of likely loadings from a Perryman Plant, water quality problems are predicted to occur. Model results show that 5X the combined nutrient loadings of Sod Run WWTP and Perryman Plant causes chlorophyll-a concentrations which exceed what are generally considered noxious levels (i.e., 80 μg/liter) during the summer months for a substantial stretch of the river in the vicinity of the proposed Perryman site. Furthermore, if conditions allow for the decay of this increased chlorophyll-a, reduced dissolved oxygen concentrations can result.

Finally, the processes which result in these high chlorophyll-a concentrations are not simply added nutrients resulting in increased chlorophyll-a production throughout the affected area. Rather, a combination of increased nutrients and the physical transport of chlorophyll-a from the vicinity of the Perryman discharge to nearby areas contributes to the increased chlorophyll-a concentrations.

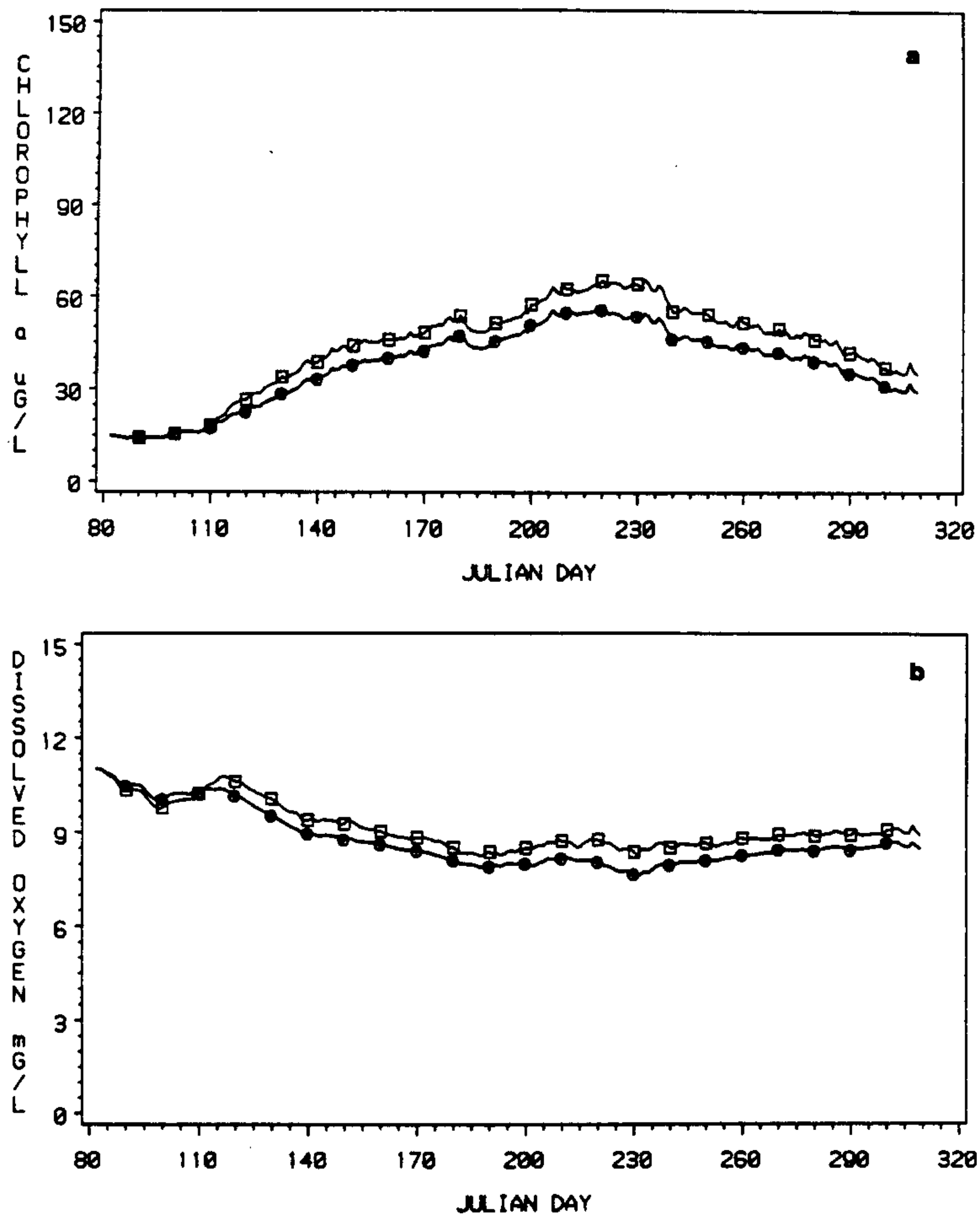


Figure V-13. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 5 for the 1984 calibration run (⊕) and the 1984 calibration run with increased nutrient loadings equivalent to Sod Run WWTP at 10 mgd and a 4-unit Perryman Plant (□).

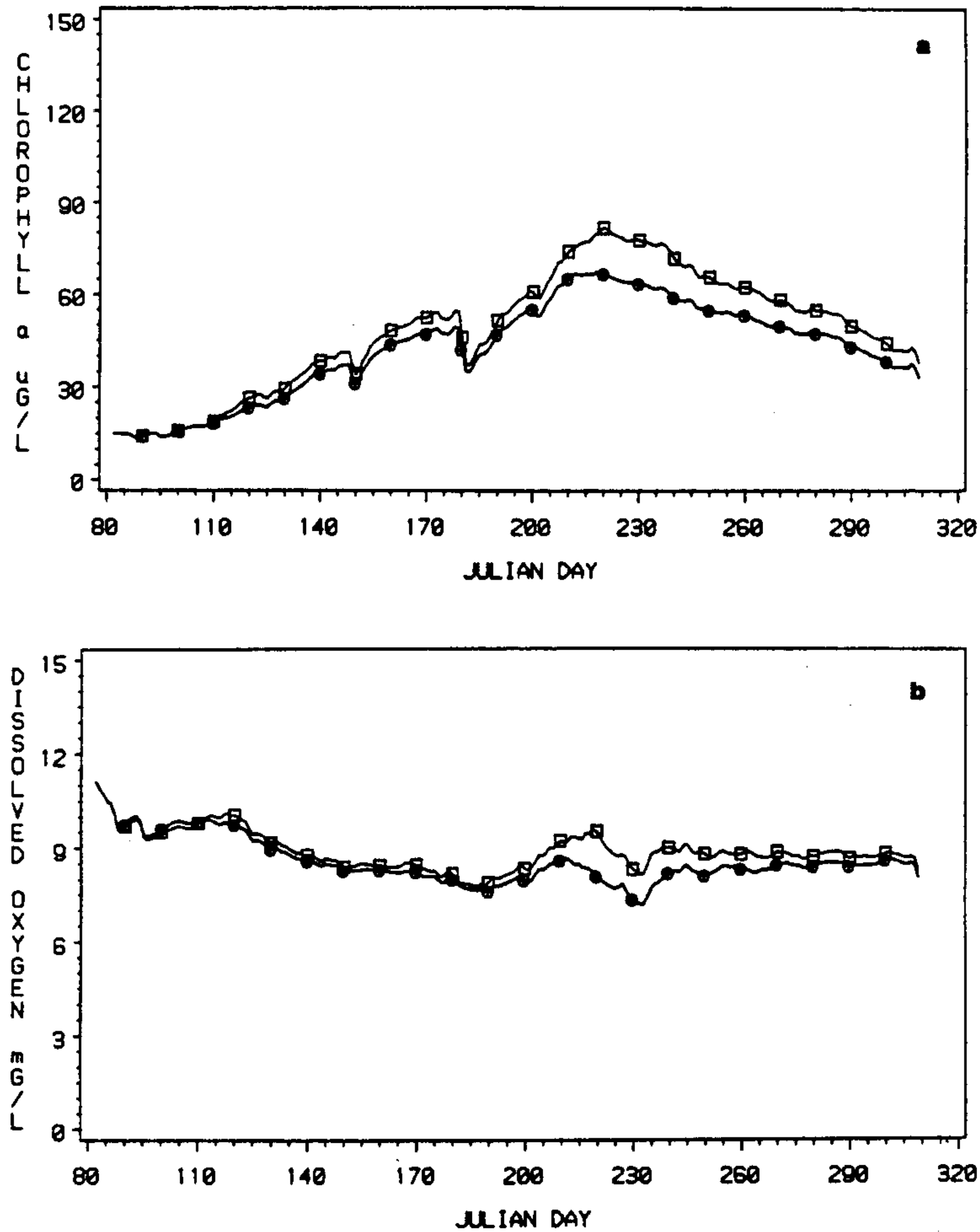


Figure V-14. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 7 for the 1984 calibration run (⊕) and the 1984 calibration run with increased nutrient loadings equivalent to Sod Run WWTP at 10 mgd and a 4-unit Perryman Plant (□).

E. PERRYMAN SCENARIOS UNDER POSSIBLE FUTURE CONDITIONS

Since the projected on-line date for the Perryman facility is 1998, the consequences of increased nutrient loadings under possible future water quality conditions in the Bush River were assessed. Two scenarios examined were the effects of increased nutrient loadings: (1) under increased Sod Run WWTP discharge, and (2) under improved water quality conditions in the Bush River. The second scenario could result from the implementation of non-point source pollution controls in the upper Chesapeake Bay region which would reduce seston and nutrient levels in the Bush River. Reduced seston and nutrient concentrations would, in turn, affect the light limitation and nutrient limitation terms that control chlorophyll-a production under present water quality conditions. The consequences of increased nutrient loadings on Bush River water quality may differ under these scenarios as compared to responses predicted for present conditions.

Increased Sod Run WWTP Discharge

Figures V-13 and V-14 show model predictions of chlorophyll-a and dissolved oxygen in Junctions 5 and 7 for the 1984 calibration run and a model run with Sod Run at 10 mgd and the assumed discharge from a 4-unit Perryman Plant.

The effects of Perryman discharge on Bush River water quality, with Sod Run WWTP at 10 mgd, are similar to the effects predicted under the 1984 calibration conditions (Sod Run at approximately 7 mgd). The increase in nutrient loadings (due to Sod Run at 10 mgd rather than 1984 values), is reflected in the slightly higher chlorophyll-a concentrations during the summertime predicted with Sod Run at 10 mgd as compared to Sod Run at 1984 values.

Improved Water Quality Conditions

Non-point source pollution controls would reduce both seston and nutrients in the Bush River watershed. Initiatives to reduce such loadings are now being fostered by federal, state, and local agencies as part of the Chesapeake Bay restoration program. To simulate these conditions, the following changes from the 1984 calibration model run were made in model inputs:

- The background light extinction parameter (BACKKE) was reduced from 0.7 to 0.2.

- The optimal light for the photosynthesis parameter (LIOPT) was increased from 5.0 to 10.0.

- The seaward constituent concentrations were set to 0.2X the values used in the 1984 calibration run.

- The tributary constituent concentrations (except DO) were set 0.2X the values used in the 1984 calibration run.

The light extinction parameter was decreased to simulate reduced seston concentrations in the water. This would result in increased light levels in the water column. Therefore, the optimal light for photosynthesis parameter would likely increase since algae would acclimate to the higher light levels. The seaward and tributary constituent concentrations were reduced to reflect improved water quality in the upper Chesapeake Bay region.

The model was run under these conditions, and also under these conditions with combined nutrient loadings corresponding to Sod Run at 10 mgd and a 4-unit Perryman Plant, and 5X the nutrient loadings from Sod Run WWTP at 10 mgd and a 4-unit Perryman Plant. Model results for chlorophyll-a and dissolved oxygen in Junctions 5 and 7 are shown in Figs. V-15 and V-16. While under the scenario of reduced seston and nutrients the model predicts much lower chlorophyll-a concentrations compared to present conditions, the effects of both levels of increased nutrient loadings parallel those based on the 1984 calibration run. The effects of a 4-unit Perryman Plant on chlorophyll-a and dissolved oxygen are small, and the model run with 5X the total nutrient load from Sod Run and Perryman results in very high chlorophyll-a concentrations. Thus, even under possible future conditions of increased Sod Run discharge and improved water quality, the likely nutrient loadings from a 4-unit Perryman Plant would have little effect on Bush River water quality.

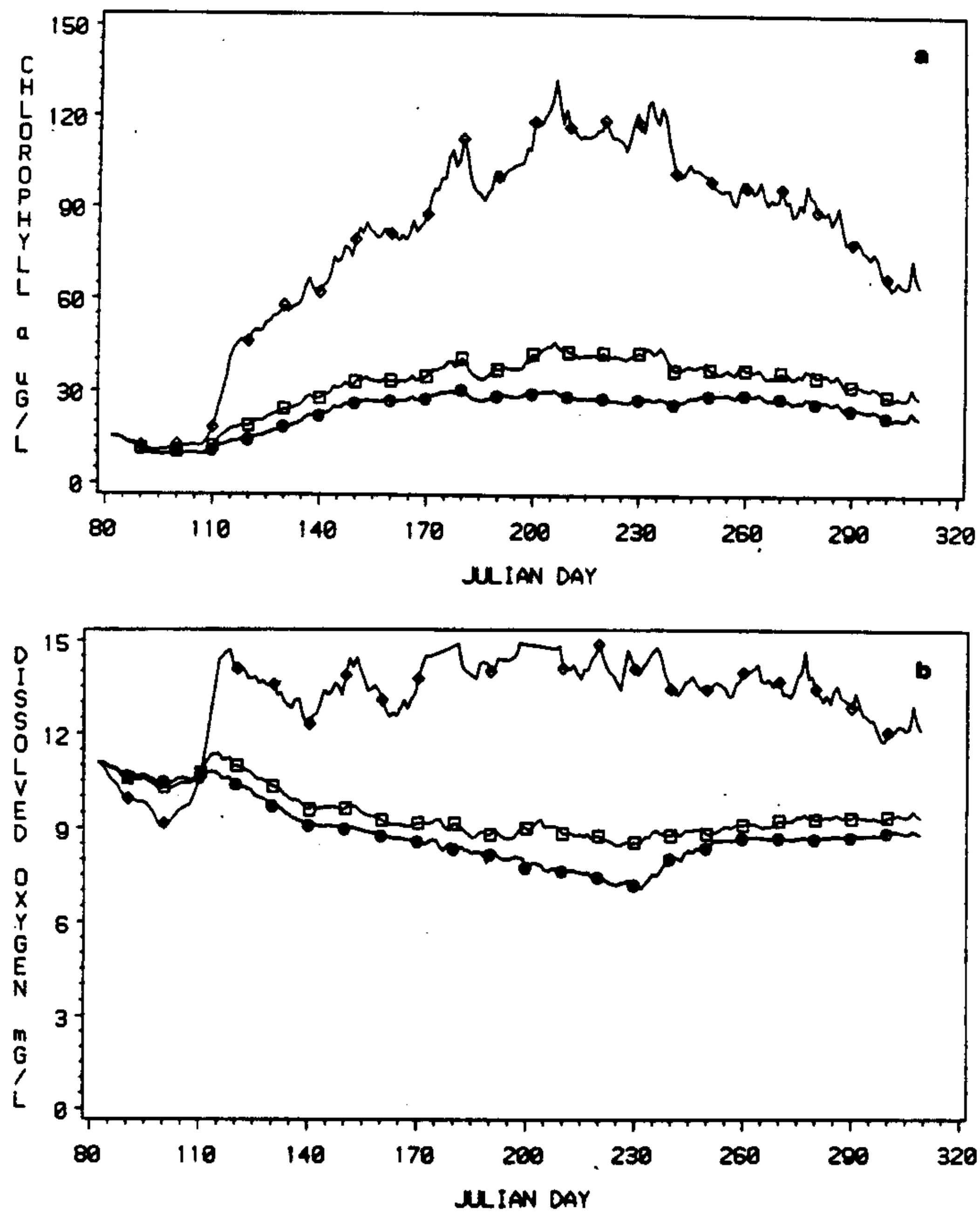


Figure V-15. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 5 for the 1984 calibration run with improved water quality conditions (⊕), the 1984 calibration run with improved water quality conditions and increased nutrient loadings equivalent to Sod Run WWTP at 10 mgd and a 4-unit Perryman Plant (□), and the 1984 calibration run with improved water quality conditions and increased nutrient loadings equivalent to 5X the combined nutrient loadings of Sod Run WWTP and a 4-unit Perryman Plant (◊ ; Constituent Loadings Level III).

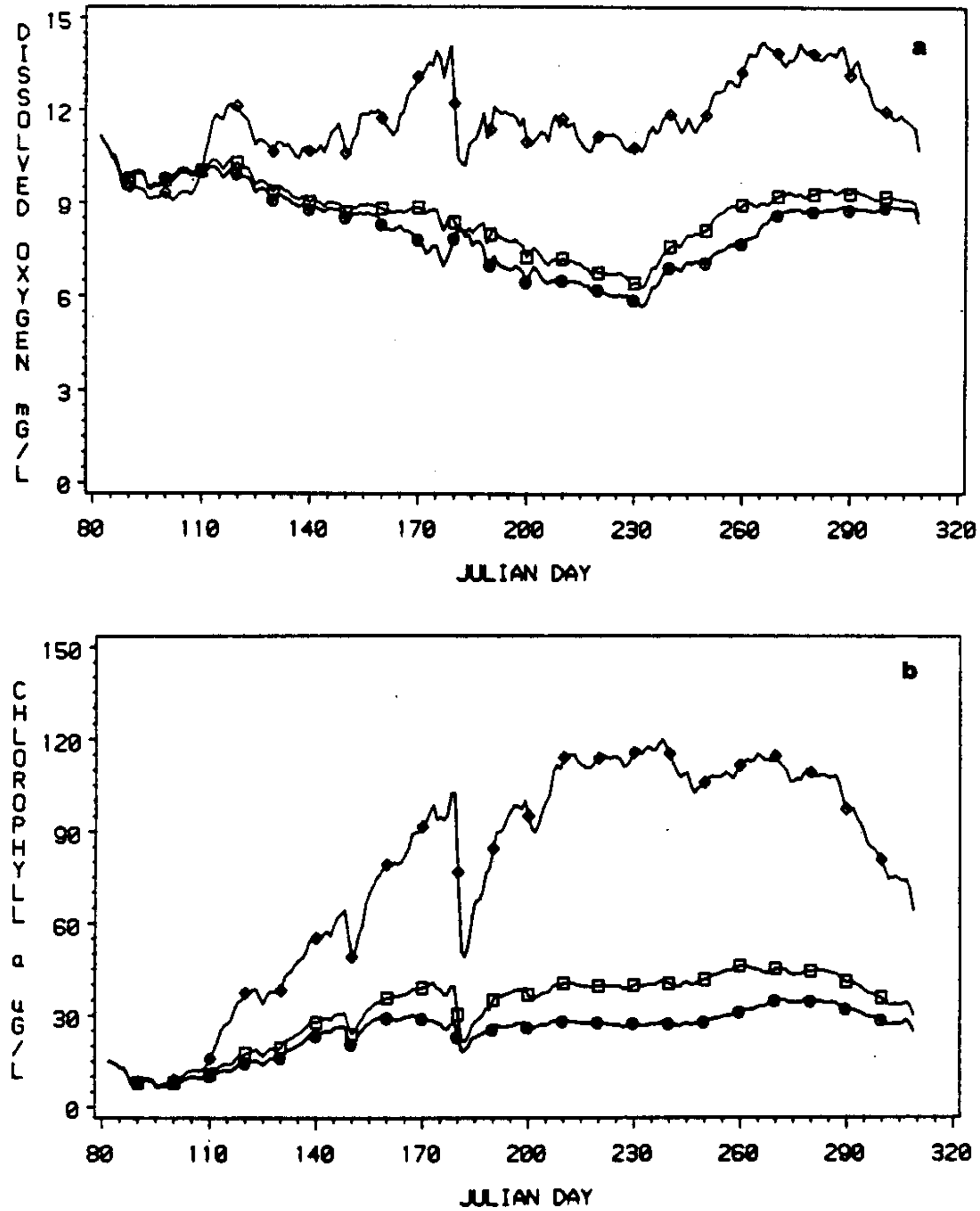


Figure V-16. Model predictions of (a) chlorophyll-a (CHLORO) and (b) dissolved oxygen (DO) in Junction 7 for the 1984 calibration run with improved water quality conditions (⊕), the 1984 calibration run with improved water quality conditions and increased nutrient loadings equivalent to Sod Run WWTP at 10 mgd and a 4-unit Perryman Plant (□), and the 1984 calibration run with improved water quality conditions and increased nutrient loadings equivalent to 5X the combined nutrient loadings of Sod Run WWTP and a 4-unit Perryman Plant (◊; Constituent Loadings Level III).